Capabilities of Print cd Reflectarray Antennas

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Abstract - This article presents an advanced antenna technology, namely the printed reflectarray, that has the potential for providing an enhanced communication capability with relatively low cost, small size and small mass. It has application in the commercial and military arenas as well as in space explorat ion.

INTRODUCTION

The printed reflectarray antenna [1,2,3] or flat reflector basically consists of a very thin, flat reflecting surface and an illuminating feed. On the reflecting surface, many printed microstrip patches or dipoles may be implemented without any power division network. The reflectarray feed illuminates the printed elements which in turn are designed to scatter or re-radiate the incident field with a planar phase front in a designated direction. The main beam of the antenna can be either fixed in a particular direction as in a passive system or can be actively scanned to cover a wide hemispherical region. The active scanning may be accomplished either electronically by implanting phase shifters into the printed elements or mechanically by using micro miniature motors underneath them. Because there is no need for low loss power dividing circuitry [1], expensive T/R modules and complicated beamformer are not needed. This is the most significant advantage of the phased reflectarray when compared to the conventional phased array. Since a large portion of the antenna, except for its feed element, is a flat structure with low profile, the antenna can be conformally mounted onto existing structure, such as a building, ship's hull, land vehicle, spacecraft, etc. Commercial application, such as the direct broadcasting satellite (DBS) service, is a good example where a flat reflector can now be conformally mounted onto the roof or wall Of a building or a residential house. For spacecraft application, the antenna's flat structure can be much more easily deployed, as compared to a parabolic reflector, to form a large aperture with relatively small stowage volume. There are other unique applications of the printed reflectarray. For an example, it can bc integrated with solar array cells on a spacecraft to save real estate and mass. A reflectarray designed with a configurable beam, other than a pencil beam, can bc achieved with a single feed horn by phasing the patch elements properly. Bandwidth and efficiency are two very important performance characteristics of the microstrip reflectarray. Calculations and measurements by several researchers have shown that the reflectarray antenna can achieve a bandwidth[4] around 10°/0 and an efficiency[5,6,7] between 50% to 70% depending on the design.

ADVANTAGES

The advantages of a microstrip reflectarray, when compared with a parabolic reflector or a conventional array are many-fold: a) Surface mountable: The reflectarray's flat reflecting surface can bc flush mounted onto its mounting structure, such as a mobile vehicle, a spacecraft, or a building. It requires less supporting structure mass and occupies less volume as compared to a curved parabolic reflector. The antenna's reflecting surface can also bc mounted conformally onto a slightly curved structure (either concave or convex). The phase deviation of the slightly curved structure can be compensated for in the design of each patch element's delay phase, b)

Scannable beam: The main beam of the antenna can be designed to point at a large fixed angle (up to 60°) from the broadside direction, while the parabolic reflector have only limited beam scan (a few beamwidths). The main beam of the microstrip reflectarray can be electronically scanned by implanting phase shifters into the phase delay lines as shown in Figure 1 or mechanically scanned[4] by miniature motors as depicted in Figure 2. With the mechanical scanning technique, complicated beamformer and high-cost T/R modules are no longer needed. c) High reliability: Since all the printed elements in the reflectarray are isolated from each other, the failure of a few elements may have insignificant impact on the performance of the antenna with thousands of elements. If 1/10 of the total elements fail to function, the antenna gain loss is only on the order of 0.5 dB. Graceful degradation in performance is certainly one significant advantage of the antenna. d) Low manufacturing cost: The reflectarray, being in the form of a printed microstrip antenna, can be fabricated with a simple and low-cost etching process, especially when produced in large quantities. e) Very large aperture antenna: Due to the fact that no power divider is needed in the reflectarray, the resistive insertion loss of thousands of microstrip patches in the reflectarray is the same as that of a few patch elements. Thus, the reflectarray can achieve relatively good efficiency as an electrically large array antenna system. f) Easily deployable: When a deployment mechanism is needed for a large aperture antenna, the flat structure of the reflectarray can be folded or unfolded by a simple hinge type of mechanism. A single or double folding, mechanism for a flat structure is approximately an order of magnitude simpler than any deployment mechanism for a curved parabolic structure and is also more reliable. The flat panel folding technique has been commonly used in the deployment of solar panels and has shown excellent reliability.

PERFORMANCE

The two most important performance characteristics of the printed reflectarray are its efficiency and bandwidth. The efficiency of the reflectarray is comparable to that of a parabolic reflector (50% - 70%). Both types of antennas have equivalent losses, such as spillover loss, aperture illumination loss, and feed insertion loss. The only loss of the reflectarray that is not associated with the parabolic reflector is its re-radiating element loss. However, for printed element, such as a single microstrip patch, this loss is generally very small and is in the order of's few tenths of a decibel. This small amount of element loss holds true across the microwave and low millimeter wave frequency bands. Recent measured results for an X-band microstrip reflectarray[7] validate the above prediction.

The bandwidth of a printed reflectarray is limited by four factors[4]. These are the element bandwidth, the element spacing, the feed bandwidth, and the spatial phase delay. Among these four, the spatial phase delay is the most crucial factor. It is caused by the path length differences between the feed to the center elements and the feed to the edge elements. These path length differences can be many multiples of a wavelength. As frequency changes, the phase change of these path length differences can be a large portion of a wavelength and thus cause the performance to degrade. Calculation[1] has shown that with proper f/D ratio of the reflector array design, a 10% bandwidth is achievable with an antenna aperture diameter of 50 wavelengths or smaller. This bandwidth can be increased by using a real time-delay-line approach to achieve the required phase delay at each element.

APPLICATIONS

Because of its low profile, small mass, and potentially lower cost, the microstrip reflectarray has several attractive applications. One is as a Ku-band Direct Broadcast Satellite (DBS) antenna. The flat reflectarray can be surface mounted on a building's side wall or rooftop as that depicted in Figure 3. Not only does it take less space, but it is also aesthetically appealing. Another application is as a DBS mobile vehicle antenna. The antenna can be mounted on the rooftop of a large vehicle, such as a van or a recreational vehicle (RV), for satellite television reception. The antenna, shown in Figure 4, has an elliptical aperture and is mechanically steered in azimuth to track the satellite as the vehicle moves about. The elliptical aperture is intended for wider elevation beamwidth so that slight yaw or pitch motion of the vehicle will not cause a significant signal fade. The third possible application arises from the fact that a reflectarray can be easily deployed to form a large aperture for space application as that depicted in Figure 5. The deploying mechanism can be the simple folding type with spring-loaded hinges. Another very large aperture antenna for space application is the reflectarray in an inflatable configuration with significantly reduced mass. The flat reflecting thin membrane surfaces (patches and ground plane) are supported by an inflated, and then rigidized, tube structure as shown in Figure 6. For spacecraft applications, very often both the antenna and the solar array panels are very large structures. It is thus advantageous to combine the two large structures into one. One technique is to use the back of the flat reflectarray for solar array. However, when both the solar array and the antenna are required to be placed on the same side of the panel, the approach of using reflectarray with printed dipoles[8], instead of patches, can be used. As illustrated in Figure 7, most of the sun light will penetrate through the dipole and the meshed ground plane layers and illuminate the solar array effectively. Another important application is that, since the amplitude and phase of the antenna aperture can be adjusted by varying the sizes of the patch elements or by varying the phase delay line lengths, the reflectarray, as a spacecraft antenna, can provide configurable shaped beams for different Earth coverages. Since thousands of elements are generally needed in a reflectarray with reasonable aperture size, the available degrees of freedom in adjusting the amplitudes and phases are much more numerous than in the case of a parabolic reflector. Thus, a configurable beam, as illustrated in Figure 8, can be more precisely synthesized and achieved by a reflectarray antenna than by a parabolic reflector.

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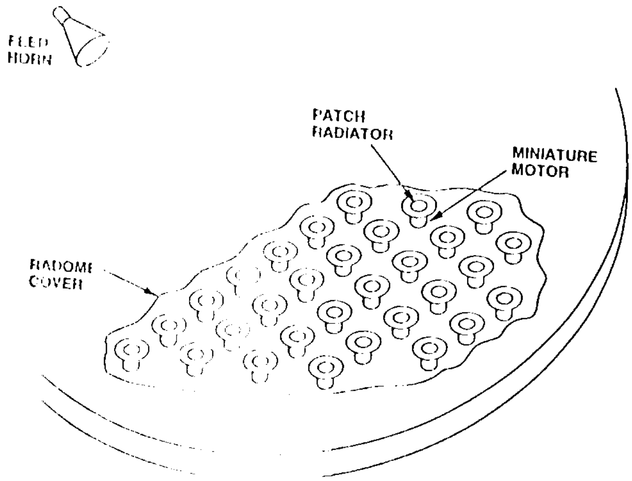

Figure 2. Configuration of printed reflectarray with mechanical beam scanning capability

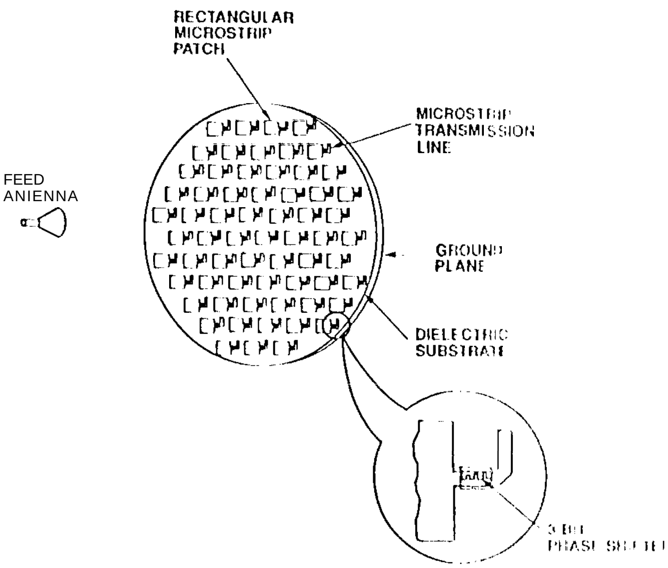

Figure 1. Configuration of printed reflectarray with electronic beam scanning capability

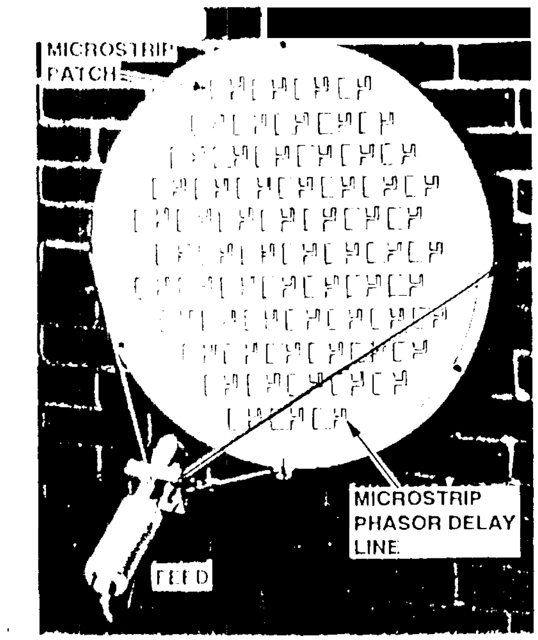

Figure 3. Side-wall mounting of printed reflectarray for DBS application

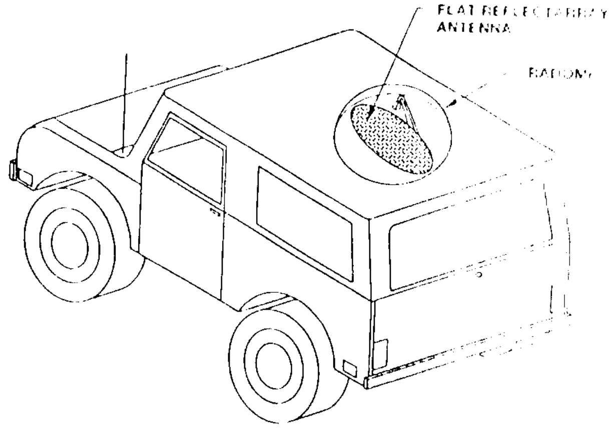

Figure 4. Land vehicle usage of printed reflectarray for DBS application

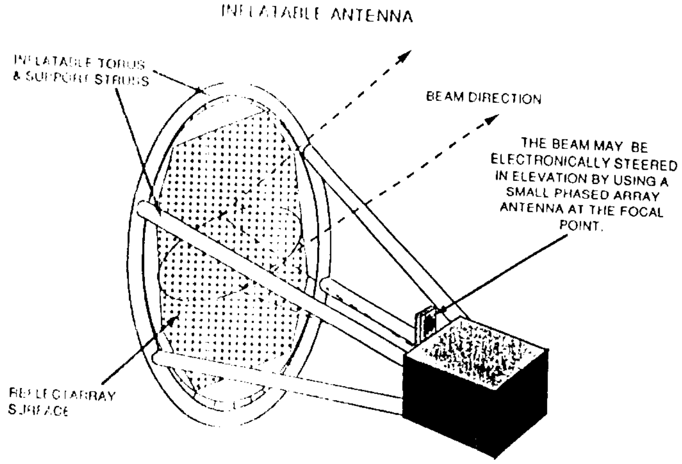

Figure 6. Inflatable large reflectarray for space application

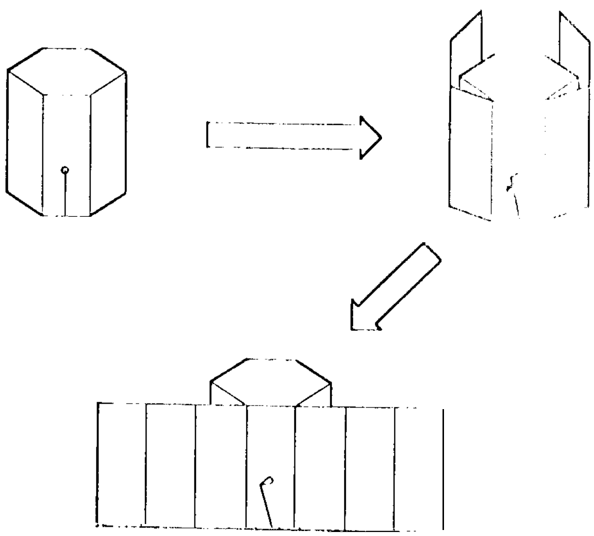

Figure 5. Flat reflectarray as simple deployable large antenna for space application

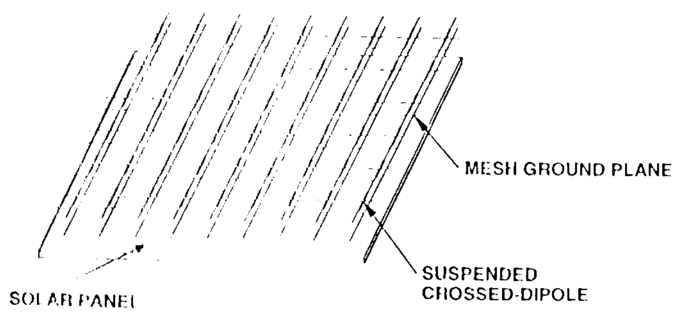

Figure 7. Printed dipole reflectarray for integrated solar-array/antenna application